# INFORMATION PROCESSING DURING HIGH AND LOW EEG ALPHA ACTIVITY

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A Thesis

Presented to

The Faculty of the Department of Psychology

The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

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by

Frances Gilliam Slocumb

1972

## APPROVAL SHEET

This thesis is submitted in partial fulfillment of

the requirements for the degree of

Master of Arts

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Approved, May 1972

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## ACKNOWLEDGMENTS

The author wishes to express her sincere appreciation to Professor Ellen R. Bauer for her patient guidance, encouragement and criticism throughout the investigation. The author is also indebted to Professors Herbert Friedman and Peter L. Derks for their encouragement and for their careful reading and criticism of the manuscript.

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## ABSTRACT

In an operant conditioning paradigm, four male subjects were trained to increase and decrease the amount of alpha (8-13 cycles per second) activity in their electroencephalograms. Reinforcement was an auditory signal which occurred whenever alpha waves were present.

After subjects achieved alpha control, they were tested on a verbal learning task for recall of word lists in high alpha, low alpha, and neutral alpha conditions.

Subjects maintained EEG patterns while the words were being presented. Recall was significantly better for subjects producing high alpha during stimulus input and significantly poorer for subjects producing low alpha. Results supported the idea of dissociation between EEG and behavioral signs of arousal.

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# INTRODUCTION

## General Background

Electrical activity of the brain, like activity of the autonomic nervous system, has traditionally been considered involuntary behavior, not under direct control of an individual. Involuntary visceral responses were believed to be subject to only Pavlovian or classical conditioning procedures, while instrumental learning was thought to modify only voluntary skeletal responses, (Kimble, 1961; Skinner, 1938). Recent evidence from bio-feedback studies indicates that these long-standing assumptions are not valid, and that electroencephalographic (EEG) and autonomic nervous system (ANS) responses can be learned in the same way that skeletal responses are learned (Miller, 1969). In bio-feedback research, electronic instruments are used which can allow a person to identify cues of internal change by transducing physiological signals into stimuli perceivable by classical sensory systems. When an individual perceives information about his own physiology, he can interact with specific parts of it and then develop voluntary control over these functions. This finding has created new interest in EEG and ANS research.

### ANS Conditioning

A series of experiments in Neal Miller's laboratory using instrumental conditioning techniques has demonstrated that animals can learn to control autonomic functions. By monitoring an autonomic variable, immediately reinforcing a response in the desired direction, and requiring progressively larger changes as the criterion for reward, ANS responses are shaped. Miller's animals learned to increase and decrease heart rate, blood pressure, intestinal contractions, rate of urine formation, and blood vessel diameter (DiCara, 1970; Dicara & Stone, 1970; Miller, 1969; Miller, DiCara, Solomon, Weiss, & Dworkin, 1971; Pappas, DiCara & Miller, 1970). Miller and DiCara controlled for the problem of voluntary muscular activity affecting visceral responses by paralyzing their subjects' skeletal muscles with a drug of the curare family. These drugs block acetylcholine, the chemical transmitter by which cerebrospinal nerve impulses are delivered to skeletal muscles, but do not interfere with consciousness or with transmitters that mediate autonomic responses (Miller, 1969). Reinforcement for changes in visceral responses was either (1) electrical stimulation of the medial forebrain bundle of the hypothalamus, a pleasure "center" in the brain, or (2) avoidance of a mild electric shock. Miller and his collaborators were able to show that their findings were not simply the result of autonomic nervous system arousal as a whole. For example, their rats learned to dilate the blood vessels in one ear only (Miller, 1969). They showed that learning of these ANS responses is specific to the autonomic response that is directly reinforced, i.e., instrumental learning of two visceral responses can occur independently of each other (Miller, 1969). Evidence for the instrumental conditioning of ANS functions has been produced in other laboratories using animals including the rat, cat, and monkey (Engle & Gottlieb, 1970; Fields, 1970; Slaughter, Hahn, & Rinaldi, 1970).

Similar results on a smaller scale have been reported in the control of human visceral responses (Brener & Kleinman, 1970; Budzynski, Stoyva, & Adler, 1970; Crider, Schwartz, & Shapiro, 1970; Delse & Feather, 1968; Katkin & Murray, 1968; Kimmel, 1967; Lang, 1970; Levine, Engle, & Pearson, 1968; Schwartz, Shapiro, & Tursky, 1971; Shapiro, Tursky, & Gershon, 1969; Shean, 1970; Shnidman & Shapiro, 1971). At Harvard Medical School, human subjects were trained to modify their blood pressure through feedback and reinforcement (Shapiro et al., 1969; Shapiro, Tursky & Schwartz, 1970; Schwartz et al., 1971). Other involuntary responses such as vomiting (Lang, 1970), skin temperature and perspiration (Crider, et al., 1970), and salivation (Delse & Feather, 1968) can be shaped in the same way as any other behavior. These results, along with those from Miller's laboratory, weaken the dichotomies of voluntary-involuntary behavior and classical-instrumental conditioning, as Miller (1963) expected they would when he first embarked on his studies.

EEG Conditioning

In addition, there is much recent evidence indicating that EEG responses in men and animals, including the alpha (8-13 cycles per second), beta (over 13 cycles per second), and theta (4-7 cycles per second) rhythms in the human can be modified through instrumental conditioning (Albino & Burnand, 1964; Barry & Beh, 1972; Beatty, 1971; Black, Young, &

Batenchuk, 1970; Brown, 1970; Bundzen, 1965; Carmona, 1967; Dewan, 1967; Green, Green, & Walters, 1970; Hart, 1968; Hord & Barber, 1971; Kamiya, 1969; Mulholland, 1968; Nowlis & Kamiya, 1970; Peper, 1970; Peper & Mulholland, 1970; Rosenfeld, Rudell, & Fox, 1969; Sterman & Wrywicka, 1967).

### Alpha Conditioning

Humans can learn to control the presence of an alpha rhythm in their electroencephalograms if given auditory or visual feedback when alpha is present (Kamiya, 1968). Using an operant conditioning paradigm with a continuous schedule of reinforcement, response-contingent feedback is the reinforcement for learning (Beatty, 1971). Kamiya (1968) and Hart (1968) used a tone signal for feedback and found that most subjects significantly increased alpha activity with ten practice sessions. Brown (1970) reported some alpha learning in a single session using a light signal for reinforcement. Subjects can learn to control not only frequency but amplitude of the EEG rhythms (Kamiya, 1969). Dewan (1967) learned to control his EEG so well that he could send messages to a computer in Morse code using his own EEG. While some subjects achieve better alpha control than others, nearly all subjects can increase the percentage of time spent in alpha. Following initial alpha feedback training, alpha control is possible without the feedback signal (Hord & Barber, 1971).

## Introduction to the Problem

What is the nature of the state in which a subject maintains a high percentage of alpha in his EEG? There have been reported numerous psychological effects of the high alpha state which usually occurs in an awake but relaxed person. Some individuals have difficulty finding the words to describe alpha after they have learned to produce it. For about half of the subjects, the mental state is that of a "content-free consciousness" (Stoyva, 1970). Some subjects report an increased awareness of thoughts and feelings, along with a pleasant feeling of well-being and tranquility (Brown, 1970, Kamiya, 1969). Some subjects describe it as a state of passive awareness, others as a feeling of floating in space, and others as a flowing with the inner and outer world (Brown, 1970; Kamiya, 1969). To many, it resembles a pleasant high similar to that associated with some drugs or with meditation (Kamiya, 1969). Not surprisingly, Zen and Yoga masters show high alpha activity (Anand, Chhina, & Singh, 1969; Kasamatsu & Hirai, 1969; Wallace, 1970).

## The Alpha Rhythm

The alpha wave is a rhythm of between 8 and 13 cycles per second with an amplitude of up to about 50 microvolts. It arises from cerebral tissue, according to the traditional view (Lindsley, 1961), and is recorded between electrodes placed at any of several locations on the scalp. Even though the nature of the relationship between EEG and cerebral function is not understood, many correlations exist between EEG activity and behavioral states (Grossman, 1967; Thompson, 1967; Venables & Martin, 1967). Fast, low-voltage beta waves are recorded in the EEG when an organism is alert and attending to stimuli. They are generally considered to be a sign of EEG arousal. While alpha waves are thought to represent synchrony in the underlying cortical tissues, beta waves are characteristic of desynchrony, or "alpha blocking" (Lindsley, 1961).

As for the physiological basis of the alpha rhythm, Andersen and Andersson disagree with the traditional view that it is a cerebral phenomenon (Lindsley, 1961) and propose a Facultative Pacemaker Theory. They hold that synchronization, or sustained alpha activity, is a thalamic phenomenon instead. While the generator of the electromotive forces is in the cortex, the available evidence, based on extensive animal studies, strongly supports the idea that the generator of the rhythmic activity of alpha waves is localized in the thalamus. They postulate facultative pacemakers at the level of the specific and association nuclei in the thalamus. From there, rhythmic discharges propagate along thalamocortical axons to induce activity in cortical cells. A certain optimal level of afferent excitation from the periphery, the cortex and other thalamic nuclei is needed to initiate alpha. An increased amount of afferent impulses beyond a critical level will desynchronize the rhythm (Andersen & Andersson, 1968).

While there is some evidence of physiological changes associated with alpha blocking (Barry & Beh, 1972), no one has yet reported physiological changes during alpha production. Hord and Barber (1971) found no correlation between heart rate and percent alpha during alpha training.

Alpha Blocking

There are differing hypotheses about the nature of alpha blocking. Lindsley's attention hypothesis states that alpha blockage is due to attention. According to his bimodal theory of arousal, there is a general arousal mechanism and a specific attention mechanism. Mulholland (1968) noted a paradox of an attention hypothesis: that after initial blocking, subjects maintain persistent occipital alpha activity when attending to an auditory stimulus. According to Peper (1970), Mulholland's Oculomotor Efferent Command Theory resolves the paradox. Rather than attention, it is an internal looking command that desynchronizes occipital alpha. A person gives "looking commands" to his eyes whenever a stimulus draws his attention (Mulholland, 1968). There is an initial alpha blockage to an auditory stimulus caused by the oculomotor component of the orienting response, but this habituates quickly. In a number of target-tracking experiments, Mulholland and Peper were not able to exclude the possibility that oculomotor functions cause alpha blockage (Peper, 1970).

Information Processing and Alpha Rhythms

While there have been isolated reports of individuals who could solve math problems (Glass, 1968; Green et al., 1970), read (Kamiya, 1969), or achieve states of intense creativity (Fermi, 1969; Stoyva, 1970), there is little experimental evidence about the information processing that occurs in the alpha state. There are bits and pieces of information that present opposing views.

That learning blocks the alpha response has been generally accepted. Thompson and Obrist (1964) monitored the EEG of their subjects during a verbal learning task and found significant changes during the learning process. They found that alpha activity decreased and beta activity increased with maximal changes occurring at the time correct responses were first elicited. They noted that these changes resembled desynchronization produced by sensory stimuli or by direct stimulation of the reticular system. They concluded that EEG desynchronization plays a significant role in the learning process. According to Lindsley (1961), ". . . low voltage, fast EEG activity indicates desynchronization, and desynchronization of neural activity suggests an increased capacity to handle information: neural elements are independent of each other and thus available to function as separate information processing channels." Albino and Burnand (1964) noted that alpha activity may be suppressed by attention or by an instruction to solve some simple problem in mental arithmetic. Mulholland (1968) stated that learning takes place in non-alpha states when one is alert and orienting.

On the other hand, some experimenters hold that EEG arousal is not a necessary concomitant of learning and that it is not closely related to degree of learning (Peper, 1970). Glass' (1968) subjects were able to maintain a fairly high amount of alpha while solving arithmetic problems. Kreitman and Shaw (1965) found evidence for enhancement of alpha in their subjects while doing mental tasks which are usually associated with alpha blocking. Andersen and Andersen (1968) predicted enhanced learning during synchronized alpha activity.

The generally accepted view has been that EEG arousal, or alpha blocking, occurs at the beginning of learning and tends to habituate as learning proceeds, suggesting that desynchronization is necessary for stimulus input (Thompson, 1967). According to Pribram (1962), processing information may desynchronize the EEG but synchrony is necessary for laying down a memory trace. Green, Green, and Walters (1970) reported that in delayed recall tests of prose stories, subjects producing the highest percentage of alpha while they were recalling remembered the most material. These ideas suggest that storage and retrieval of information not only may occur during synchronized EEG activity but may also be enhanced.

If alpha can be maintained during stimulus input as well as during storage and retrieval, desynchrony may not be a necessary concomitant of learning. Behavioral activation may be necessary but there is considerable evidence that the EEG is not a perfect measure of activation. The two types of measures are dissociated, for example, when atropine is administered to animals. An animal remains awake and alert even though the EEG is one of permanent sleep (Thompson, 1967). Paradoxical sleep is another case of dissociation between behavioral and EEG signs of arousal. EEG arousal sleep is a deeper sleep than is that showing synchronized spindling (Thompson, 1967). Lesion studies provide additional evidence for this dissociation. Extensive destruction of the posterior hypothalamus in cats produces an animal in a permanent coma even though cortical EEG arousal can be induced (Thompson, 1967). Thus the necessary behavioral arousal may exist for learning even though there is synchrony in the EEG.

The questions raised by this study were: Once alpha control is established, can it be dissociated from other cognitive activity? Is verbal learning possible in a high alpha state? Is it possible for a subject to maintain high alpha EEG patterns while actively processing information?

Memory Model

These problems were investigated using the Atkinson and Shiffrin (1968) model of human memory which distinguishes between three memory stores: the sensory register, the short-term store, and the long-term store. The first is the store which receives information from the sense organs and from which information decays very rapidly. The short-term store temporarily holds information that has entered it from the sensory register. To prevent forgetting by spontaneous decay from occurring here, subjects must rehearse information so that it remains long enough to be transferred to the long-term store. When subjects are given a word list and asked for free recall, items in the last several positions on the list are assumed to be recalled from the short-term store. The shape of the serial position curves can provide information concerning the nature of information processing. A recency effect can be seen when recall for these last few words is enhanced. Items recalled from the first few positions of a list represent information recalled from the long-term store. The primacy effect is shown by enhanced recall of early items.

The purpose of the present experiment was to determine whether trained subjects could maintain alpha and at the same time perform a verbal learning task; and if so, to investigate learning in the various stages of information processing during high and low alpha activity.

## METHOD

Subjects. Subjects were four male college students, ages 17-21, chosen from a group of volunteers for showing a high initial baseline for occipital alpha with eyes closed. Only male subjects were used in this study because there is evidence that women have less alpha activity than men (Glass, 1968). After they were chosen, subjects were informed that they would be paid $1.65 an hour for participating in the experiment.

Baseline alpha was measured on approximately twenty-five people. Of the eleven who were chosen for training, only four reached criterion in the time allowed for training, which was ten weeks. Of the other seven, three dropped out and training for four was terminated by the experimenter. Three of the latter began training four to five weeks later than the first subjects and did not acquire a sufficient amount of control to be used as subjects. There is no reason to think that with sufficient training they would not have reached criterion. The fourth subject was dropped because his performance steadily worsened after he attained a certain initial amount of control. Continuation for him would have probably been more uncomfortable than having his training discontinued. While the reason for this subject's difficulty is unknown, one can speculate that there might have been either (1) a motivational problem, or

(2) an aversive response to the sound of the feedback, or (3) too great an effort to do well. It is commonly observed that subjects who try too hard have the most difficulty in achieving alpha control (Kamiya, 1968).

Apparatus. The Toomim Alpha Pacer (Model 420, Toomim Bio-Feedback Laboratories, 41 West 71 Street, 6B, New York, New York) was used to train subjects to produce and suppress occipital alpha activity. With this instrument, subjects were placed in a feedback loop with continuous reinforcement so that every time an alpha wave of 8-13 cycles per second occurred, a tone was produced. Bipolar recordings were made with gold plated electrodes attached to a nylon headband.

The amplified EEG signal was recorded from the Alpha Pacer on one channel of a Grass Model 7 Polygraph. A manually operated double-pole switch was used to simultaneously mark alpha periods on the EEG and accumulate times on a Hunter Klockounter (Model 120A).

During all training and test sessions subjects were seated in a dental chair with their heads supported. Word lists and instructions for training and tests were tape recorded and played on a Sony cassette recorder.

The Polygraph and clock were monitored by an undergraduate assistant in a room adjacent to the training and testing room. A microphone in the testing room connected to a speaker in the adjacent room allowed the assistant to monitor sessions. She recorded times from the clock at two-minute intervals during training sessions and marked stimulus events on the EEG record during testing.

Procedure. When prospective subjects reported for baseline measurement, the experimenter explained the general nature of the experiment (see Appendix for instructions). They were told that after alpha training, subjects chosen would be tested on a verbal learning task. While electrodes were being applied, the experimenter gave a brief explanation of how electrical activity of the brain is measured. Baseline alpha was monitored by the experimenter using an earphone connected to the Alpha Pacer so that subjects did not hear the feedback tone. Those subjects with an abundance of alpha activity at an amplitude of 10-15 $\mu$v., and who were interested in continuing, were chosen for training.

On each day of training and testing, subjects were seated in the dental chair, at a slight recline, in a sound-deadened room, facing away from the experimenter. Each day, the experimenter gave a brief explanation of the procedure for the day. Bipolar electrodes were attached in an occipital-frontal plane with the ground electrode placed above the right ear. After electrodes were attached, the light in the room was lowered. Subjects were instructed to close their eyes during training and testing sessions, to remain still, and to try to avoid any vigorous movements of eyes or body.

The first two training days began with a rest period during which subjects were instructed to relax and listen for ten minutes to the tone which indicated the presence of alpha. It was produced by an internal standard in the Alpha Pacer. Following the rest period, and on all subsequent training days, there was a 20-minute training period of ten two-minute intervals with taped instructions to produce ("start") and suppress ("stop") alpha activity during alternate intervals. Three training sessions were scheduled each week for each subject and some subjects practiced on their own between sessions.

For initial training sessions, the amplitude threshold was set at 15$\mu$ v. so that alpha waves of at least that amplitude were required to trigger the tone. As discrimination and control were accomplished, the amplitude threshold setting was gradually increased. Each subject was trained to control alpha with eyes closed to the following criteria: to produce alpha at amplitudes of 25 $\mu$v. or greater so that 55% or more of each high alpha trial was producing a tone; to suppress alpha at 25 $\mu$v. or less so that no more than 10% of each low alpha trial produced a tone.

During training and testing, when the feedback tone occurred, the experimenter pressed a switch which activated the clock and marked the event as reinforced alpha on the EEG record. Alpha time was read to the nearest second from the Hunter Klockounter at two-minute intervals for each 20-minute session. After each interval, the counter was reset to zero and a record for the next two-minute interval was started.

To get a reliability estimate, another judge of reinforced alpha (tone on) simultaneously marked the event on the EEG record at the same time that the experimenter was marking it. Samples of the event as marked by experimenter and judge, were measured from the EEG record and compared. The independent judgements were highly correlated ($r=.975$, $p= <.001$).

Abundance of alpha activity present in the EEG was derived from the counter since it was only on when alpha activity was present. The total amount of time that alpha activity was present was determined for the total duration of on and off sessions each day and was recorded as percentage of the time allowed for each condition.

Following training, all subjects were tested on a verbal learning task under three instructions conditions: High Alpha (HA), Low Alpha (LA), and Neutral, or Control Condition (CC). In the HA and LA conditions, subjects were instructed to produce or suppress alpha at the sound of a signal, and to maintain the condition while stimulus words were being presented. For the CC condition, subjects were instructed to make no effort to produce or suppress alpha activity while the words were being presented. Subjects received no alpha feedback during testing. Alpha production was monitored and timed. Subjects were given practice trials under all conditions on one day before testing. All subjects were tested in the control condition (CC) on the first and fourth days. Conditions HA (high alpha) and LA (low alpha) were counterbalanced for subjects on days two and three, so that two subjects were tested first in the HA condition, and two were tested first in the LA condition.

Ten taped word lists of nine words each were presented on each day in blocks of 5 lists. Words in each list were presented with an interstimulus interval of one second. All subjects heard the same taped words, each presented only one time to a subject, with order of block presentation randomized across conditions. Four- and five-letter words of moderate concreteness and frequency, and easily pronounced, were chosen from master lists of frequently used English words (Carroll & Davis, 1971; Pavio, Yuille, & Madigan, 1968; Thorndike & Lorge, 1944). In any nine-word list, the first letter of every word was different, the initial letter of one word did not naturally follow the initial letter of the previous word, and words having obvious association value were not located together in a list (see Appendix).

The events of a testing session occurred in the following order: EEG instructions, delay of no less than 15 seconds for establishing EEG pattern, list presentation, signal to end effort to maintain EEG pattern and to begin oral free-recall (45 seconds for recall). After an intertrial interval of no less than 90 seconds, the next trial was presented in the same manner. Two "start" and "stop" warm-up trials were given prior to testing in HA and LA conditions.

After testing, subjects were asked to specify the conditions under which they thought learning was best and worst. They were also asked to describe how they produced and suppressed alpha activity and the feelings that they experienced in each condition.

## RESULTS

### Alpha Control During Training

Degree of control over alpha was quantified by computing the number of seconds that the tone indicative of alpha was sounding and calculating the percentage of time alpha was present (the Alpha Index) under each condition on each day.

Trials to criterion for the four subjects varied considerably: approximately 8, 10, 11, and 24 training sessions. Criterion was defined as production of alpha at an amplitude of at least 25 $\mu$v. so that 55% or more of each high alpha trial was producing a tone, and suppression of alpha at amplitudes of 25 $\mu$v. or less so that no more than 10% of each low alpha trial produced a tone. Figure 1 shows two typical EEG's at the beginning of Day 1 training. By the end of Day 1, all subjects were discriminating; they were producing more alpha during "on" trials than during "off" trials. Figure 2 shows typical EEG changes at "start" and "stop" instructions after alpha control was established. There is a noticeable difference between waveforms of alpha "on" and alpha "off."

To determine whether there was a change in alpha baseline after training, the Alpha Index for the first four trials of Day 1 training (equivalent to baseline) was compared to the Alpha Index in the Neutral

FIGURE 1

EEG RECORDS BEFORE ALPHA TRAINING

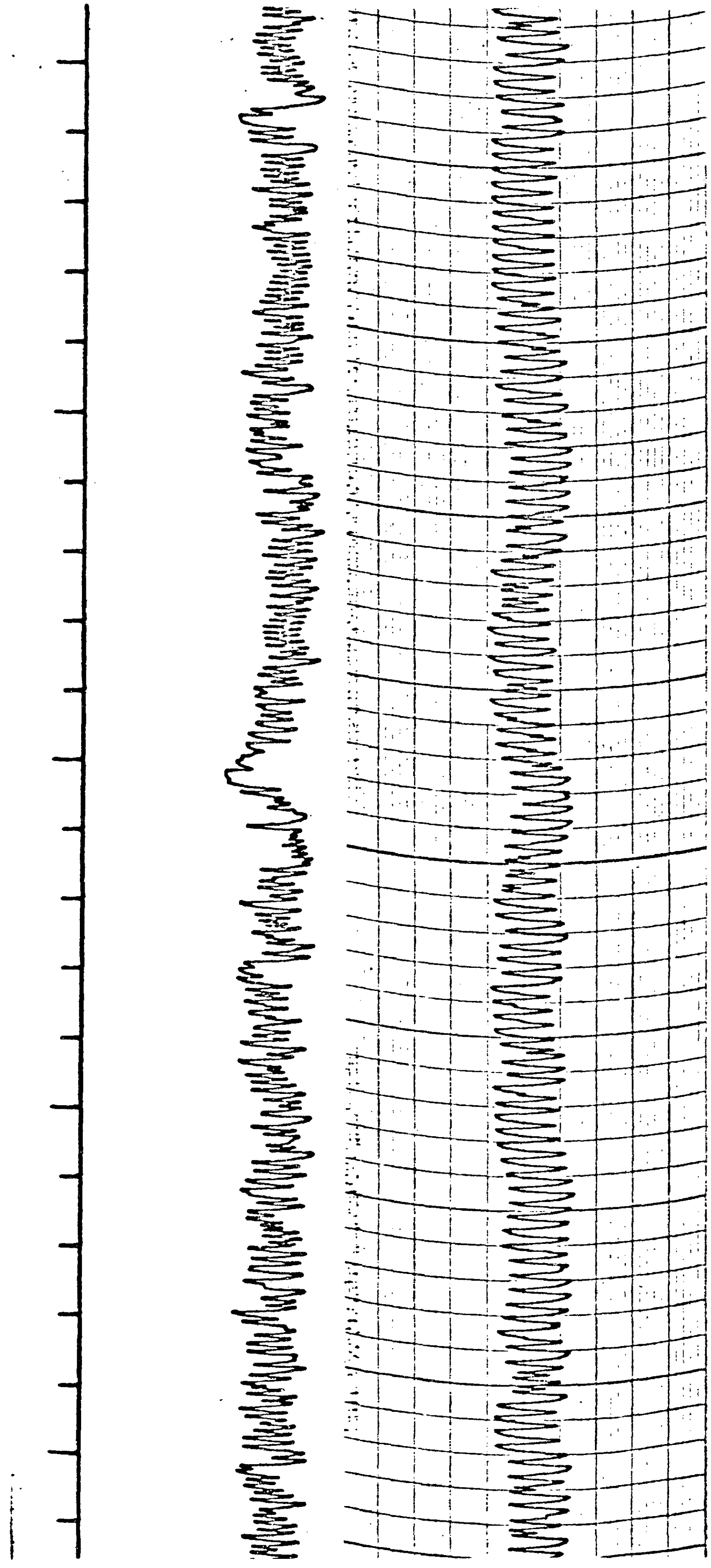
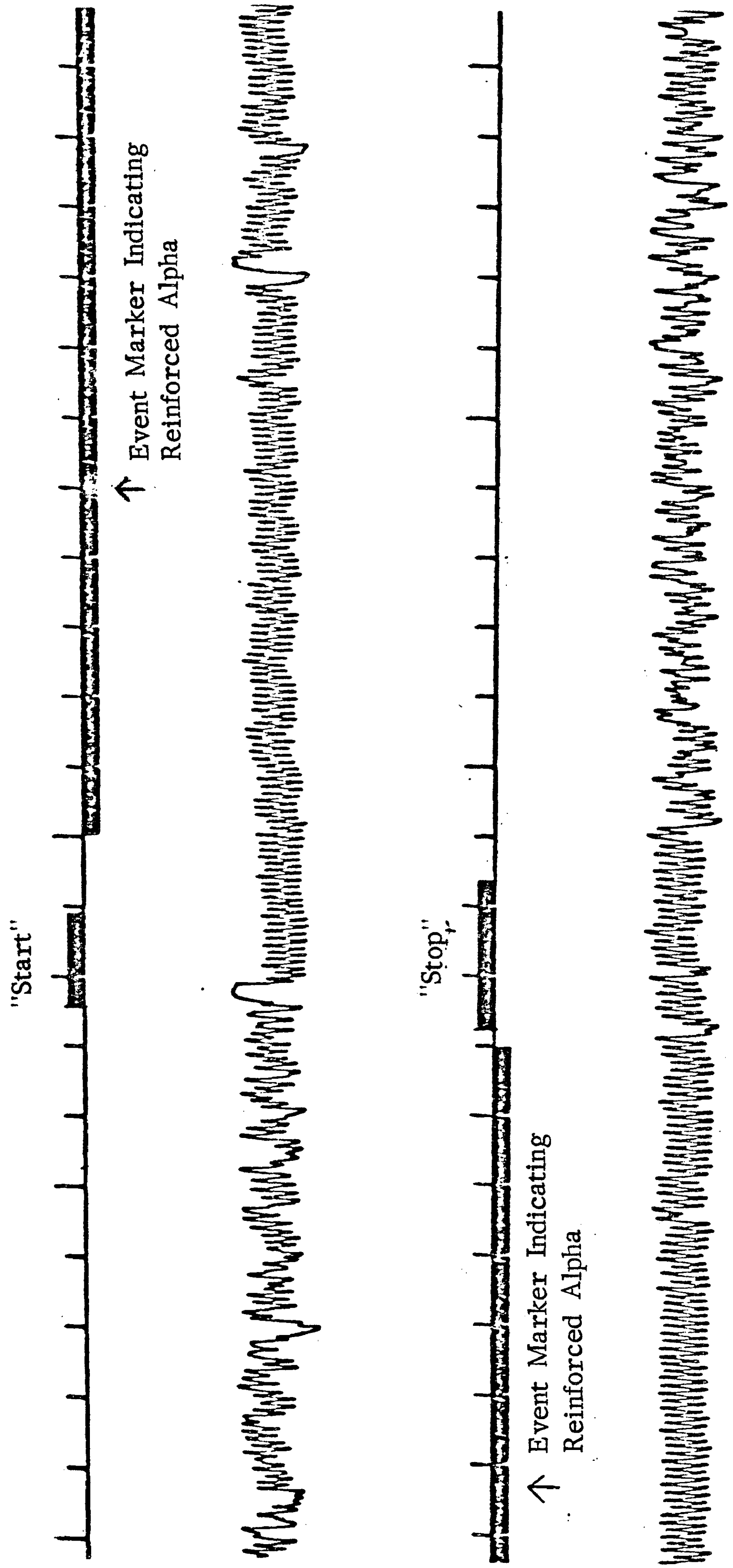


FIGURE 2

EEG RECORDS AFTER TRAINING



"Start"
Event Marker Indicating
Reinforced Alpha
"Stop"
Event Marker Indicating
Reinforced Alpha

condition of testing. A statistical analysis comparing these days, with a less stringent criteria being used the first day, revealed significant differences ($t=14.9$, $df=1$, $p= < .05$). Data from only two subjects were used for this analysis since the other two subjects were partly pretrained.

Alpha Control During Testing

An examination of both practice and testing trials reveals no evidence of an orienting or alpha blocking response while words were being presented. All subjects were able to maintain EEG patterns as instructed during stimulus input. The mean Alpha Index, or percent time in alpha, as shown in Table 1, was considerably better than criterion requirements in both conditions HA (high alpha) and LA (low alpha). The Alpha Index in the Neutral condition (CC) was high for all subjects, although not as high as that in HA (high alpha). Figure 3 shows the EEG of all subjects on the first testing trial under high alpha instructions. The steady alpha rhythms before words were presented was not interrupted by the stimuli.

A one-way repeated measures analysis of variance on the Alpha Index during testing showed significant differences in percentage of time spent in alpha between treatments, as shown in Table 2. Tukey's HSD (honestly significant differences) Test for comparison between all pairs of means revealed significant differences between the LA condition and the other conditions. As shown in Table 3, there was significantly less alpha under low alpha instructions. Differences in the Alpha Index between HA and CC conditions were not significant, although subjects tended to produce more alpha in the high alpha condition.

TABLE 1

MEAN ALPHA INDEX DURING TESTING

| | High Alpha (HA) | Low Alpha (LA) | Neutral (CC) |
|---|---|---|---|
| $S_1$ | 74.9% | 13.8% | 70.6% |
| $S_2$ | 96.1% | 5.9% | 89.45% |
| $S_3$ | 94.1% | .5% | 69.95% |
| $S_4$ | 90.2% | .7% | 50.95% |

FIGURE 3

EEG RECORDS OF FIRST TESTING TRIAL

IN HIGH ALPHA

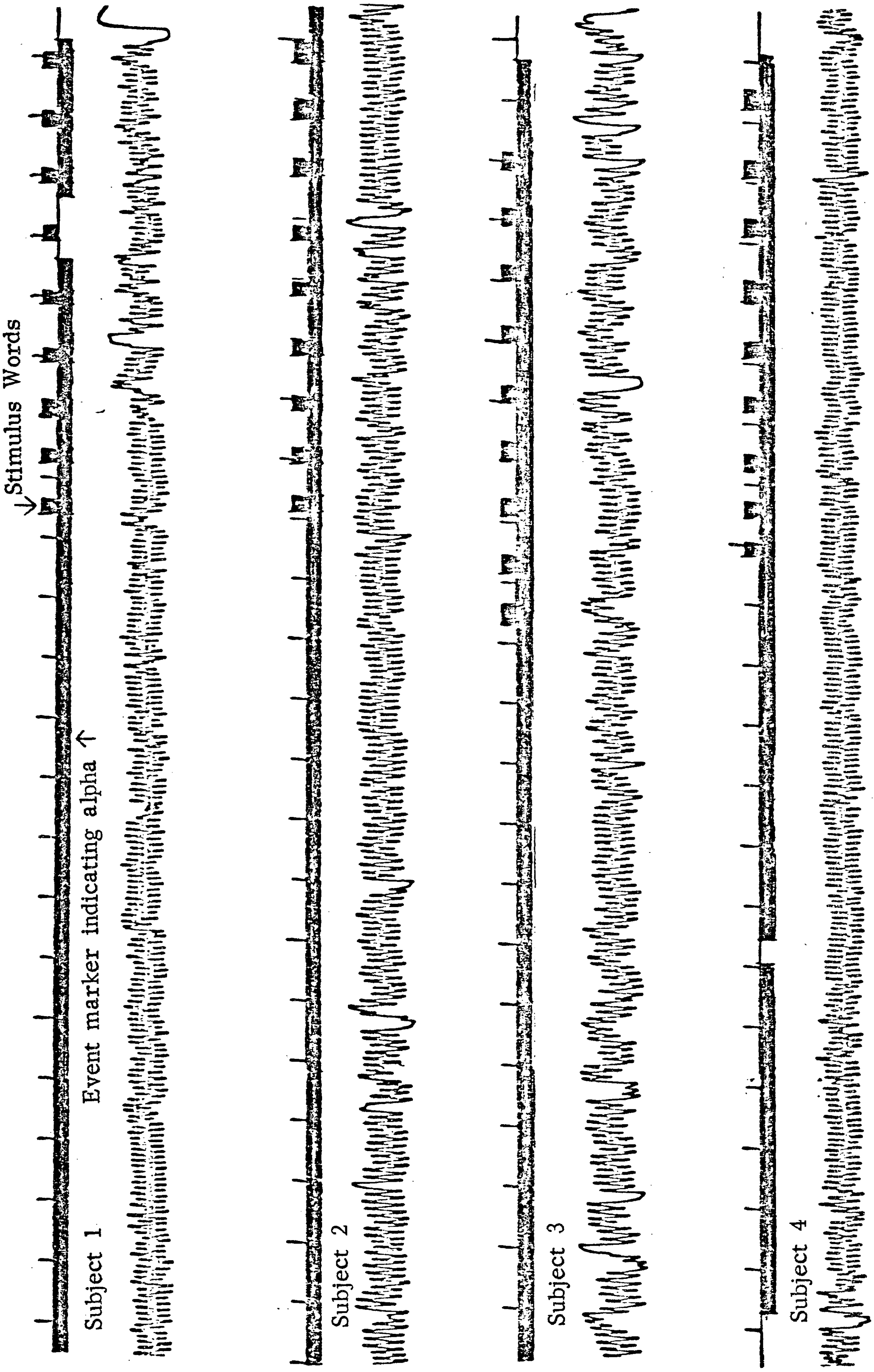

Stimulus Words
Event marker indicating alpha
Subject 1
Subject 2
Subject 3
Subject 4

TABLE 2

SUMMARY TABLE FOR ANALYSIS OF VARIANCE

IN ALPHA INDEX DURING TESTING

| Source of Variance | df | Mean Squares | F |
|---|---|---|---|
| Between Treatments | 2 | 7707.38 | 64.89* |
| Between Subjects | 3 | 140.68 | 1.18 |
| Residual | 6 | 118.77 | |
| Total | 11 | | |

* $p < .01$

TABLE 3

DIFFERENCES BETWEEN ALPHA INDEX MEANS

| Condition | | Low Alpha | Neutral | High Alpha |
|---|---|---|---|---|
| | Mean | 5.23 | 70.24 | 88.83 |
| Low Alpha | 5.23 | - | 65.01* | 83.60* |
| Neutral | 70.24 | - | - | 18.59 |
| High Alpha | 88.83 | - | - | - |

* $p < .05$ for differences greater than 23.64

## Recall

The dependent variable in this study was number of words recalled. Data from the two Neutral conditions were pooled because a t-test revealed no significant differences between them ($t=.63$, $df=3$, $p > .25$). Table 4 shows the mean number of words recalled under each of the three test conditions for each of the four subjects. Recall was significantly better in high alpha and significantly poorer in low alpha than in the other conditions. An analysis of variance with repeated measures on both factors on the number of errors in serial positions under each of the instructions conditions revealed significant main effects for Instructions and for Serial Positions, as shown in Table 5. There was no interaction. Tukey's HSD Test was used for making all possible comparisons among means for each main effect. There were significant differences between means of all Instructions conditions, shown in Table 6.

The above analysis permitted a comparison among means for serial positions using Tukey's HSD Test, shown in Table 7. There was a significant difference between recall in position 9 and recall in all other positions. Recall of the last word in the lists was significantly better than recall of any other words. Recall in positions 2, 3, 4, 5, and 6 was significantly poorer than that in positions 1, 7, 8, and 9. There were no significant differences between recall in positions 1, 7, and 8. That recall was better for words in position 9 than for words in position 1 indicates that there was a stronger recency effect than primacy effect.

Recall data from $S_1$ was lower than that of other subjects, due to a

TABLE 4

NUMBER OF WORDS RECALLED AVERAGED ACROSS

ALL NINE-WORD LISTS

Instructions Condition

| | | HA | LA | CC |
|---|---|---|---|---|
| | $S_1$ | 2.8 | 1.1 | 2.1 |
| Subject | $S_2$ | 4.9 | 4.8 | 4.4 |
| | $S_3$ | 6.6 | 5.7 | 5.8 |
| | $S_4$ | 5.9 | 4.6 | 5.9 |

TABLE 5

SUMMARY TABLE FOR ANALYSIS OF VARIANCE ON ERRORS

| Source of Variance | df | Mean Square | F |
|---|---|---|---|
| Subjects | 3 | 106.68 | 27.57** |
| Treatments | 26 | 8.05 | |
| Instructions (A) | 2 | 12.29 | 3.17* |
| Serial Positions (B) | 8 | 20.01 | 5.17** |
| Interaction (AB) | 16 | 1.55 | .40 |
| Residual | 78 | 3.87 | |
| Total | 107 | | |

* $p < .05$

** $p < .01$

TABLE 6

DIFFERENCES BETWEEN TREATMENT MEANS

| Treatment | | High Alpha | Neutral | Low Alpha |
|---|---|---|---|---|
| | Mean | 17.33 | 19.88 | 22.0 |
| High Alpha | 17.33 | - | 2.55* | 4.67* |
| Neutral | 19.88 | - | - | 2.12* |
| Low Alpha | 22.00 | - | - | - |

* $p < .05$ for differences greater than 1.112

TABLE 7

DIFFERENCES BETWEEN SERIAL POSITION MEANS

| Serial Position | | 9 | 8 | 1 | 7 | 6 | 2 | 4 | 3 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | 9.83 | 16.17 | 16.50 | 17.17 | 20.67 | 24.00 | 24.33 | 24.33 | 24.67 |
| 9 | 9.83 | - | 6.34* | 6.67* | 7.34* | 10.84* | 14.17* | 14.50* | 14.50* | 14.84* |
| 8 | 16.17 | - | - | ..33 | 1.00 | 4.50* | 7.83* | 8.16* | 8.16* | 8.50* |
| 1 | 16.50 | - | - | - | .67 | 4.17* | 7.50* | 7.83* | 7.83* | 8.17* |
| 7 | 17.17 | - | - | - | - | 3.50* | 6.83* | 7.16* | 7.16* | 7.50* |
| 6 | 20.67 | - | - | - | - | - | 3.33* | 3.66* | 3.66* | 4.00* |
| 2 | 24.00 | - | - | - | - | - | - | .33 | .33 | .67 |
| 4 | 24.33 | - | - | - | - | - | - | - | 0.00 | .34 |
| 3 | 24.33 | - | - | - | - | - | - | - | - | .34 |
| 5 | 24.67 | - | - | - | - | - | - | - | - | - |

* $p < .05$ for differences greater than 2.584

hearing deficit that became apparent at the time of testing. That the deficit was in hearing and not in memory was established by administering a taped list of 25 words, each of which was repeated by the subject as soon as he heard it. While the other three subjects heard 95-100% of the words correctly, $S_1$ heard only 25% correctly. An additional 50% of the words he reported shared at least one phoneme with the test word. Since each subject served as his own control, data from $S_1$ were included in the analysis.

Serial position curves were similar for all subjects with the exception of $S_1$, whose curves were flatter, showing a greater deficit in earlier serial positions, as seen in Figure 4. Curves summed over four subjects and shown in Figure 5 are all typical serial position curves. There are clearly primacy and recency effects in all three curves.

Subjective Evaluation

Subjective evaluation of recall can be seen in Table 8. While all subjects tended toward better performance in high alpha, only two thought that they did. The other two subjects thought that their recall in the Neutral condition was superior. Only two subjects thought that their recall in the low alpha condition was poorest, while in fact, all four subjects recalled fewer words when they were suppressing alpha during stimulus input.

The subjects' reports of what they did to produce or suppress alpha, and how each state felt, yielded no consistent pattern for gaining control. In describing how they produced alpha, responses ranged from concentrating

FIGURE 4

SERIAL POSITION CURVES FOR $S_1$

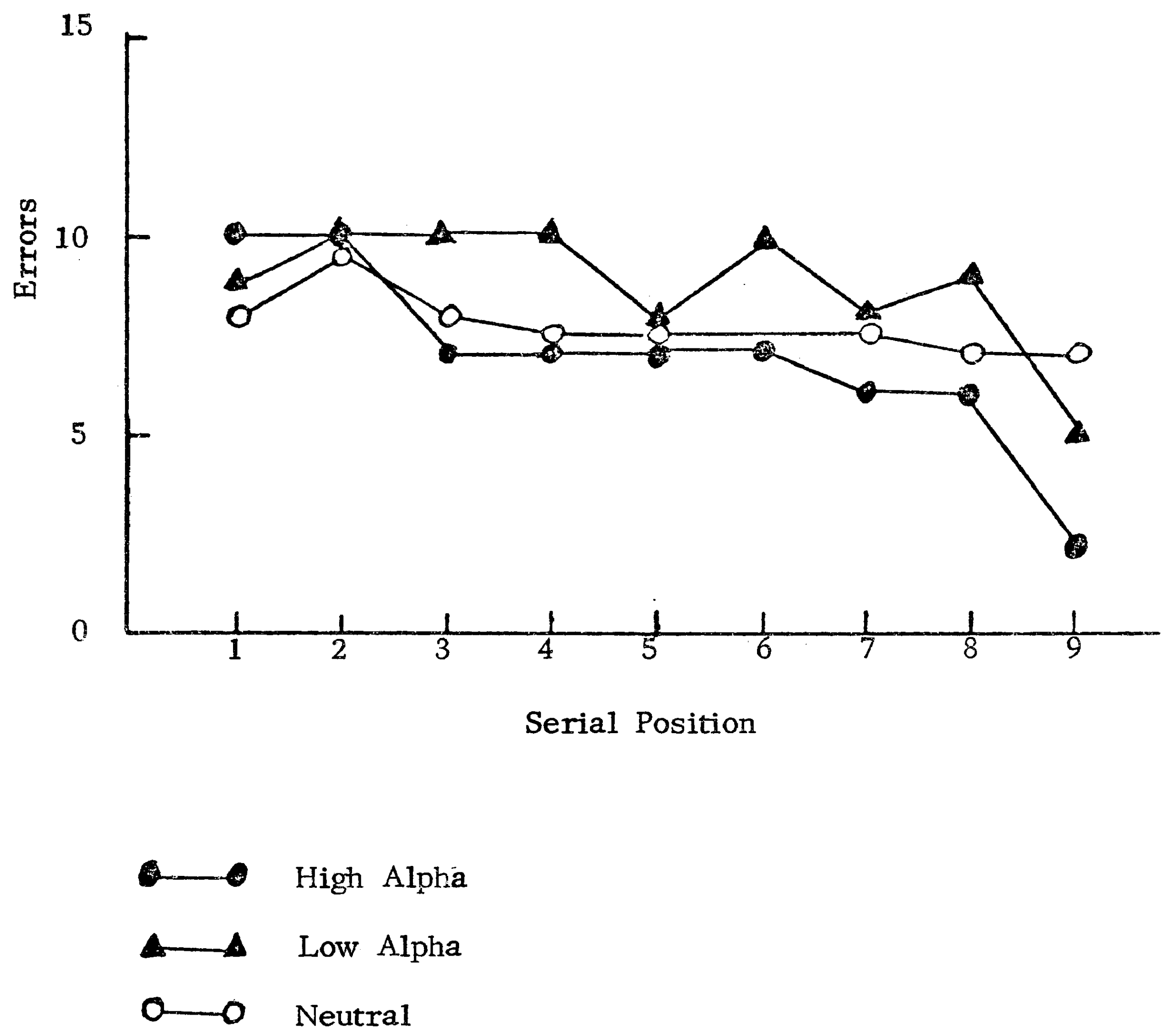

15
10
5
0
Errors
1
2
3
4
5
6
7
8
9
Serial Position
High Alpha
Low Alpha
Neutral

FIGURE 5

SERIAL POSITION CURVES SUMMED

OVER FOUR SUBJECTS

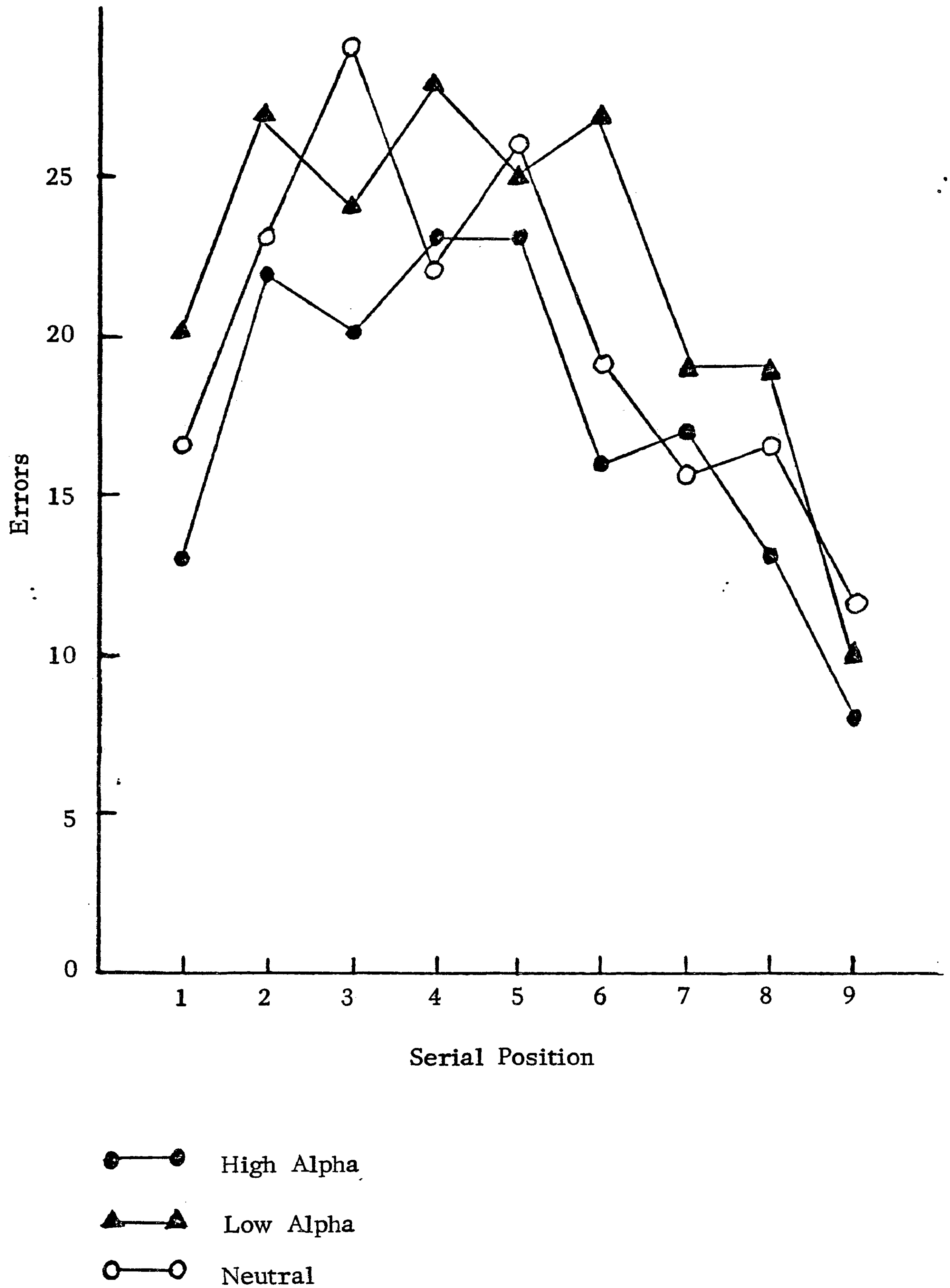

25
20
15
10
5
0
Errors
1
2
3
4
5
6
7
8
9
Serial Position
High Alpha
Low Alpha
Neutral

TABLE 8

A COMPARISON OF ACTUAL RECALL WITH SUBJECTIVE ESTIMATES OF RECALL

| | Actual Recall | | | | Subjects' Estimates | | | |
|---|---|---|---|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ |
| Best | A | A | A | A, C | C | A | A | C |
| Neutral | C | C | C | | A | C | B | B |
| Worst | B | B | B | B | B | B | C | A |

to not concentrating; from letting thoughts drift through the mind to "forcing a stream of thought through my head." All agreed that relaxation was helpful and that producing alpha gave a pleasant feeling, sometimes like floating, drifting or spinning. In describing how they suppressed alpha, replies ranged from concentration on visual images to "concentrating on unpleasant things." All subjects except one agreed that suppressing alpha was uncomfortable. The other subject reported a feeling of being awake, but nothing unusual while suppressing alpha.

# DISCUSSION

That subjects were able to maintain high alpha activity while words were being presented is a finding contradictory to the prevalent view about EEG activity during stimulus input. That they recalled better after producing high alpha during stimulus input than they do under normal circumstances also contradicts the traditional view (Lindsley, 1961) about optimal conditions for learning.

## Recall

In addition to showing a greater amount of alpha activity, subjects in the high alpha and neutral conditions showed significantly better recall than did subjects in low alpha. Although they were not told what the experimenter expected to find, they probably formed their own hypotheses about the expected outcome (Rosenthal & Rosnow, 1969). Better learning in high alpha may reflect hypotheses in that direction. On the other hand, differences between high and low alpha learning may be real. If there is a difference, it is only one of degree, since serial position curves for the three conditions were essentially of the same shape. One might reasonably argue that subjects in the low alpha condition would have performed better had there been more beta activity in their EEG's. Low amplitude, high frequency beta is thought to be best for learning

(Lindsley, 1961). An examination of EEG's during low alpha instructions, as seen in Figure 2, shows little low amplitude high frequency activity, indicating that there was little beta present.

Attention

Lindsley's widely-accepted attention hypothesis (1961) holds that a sound stimulus blocks alpha. A desynchronized EEG is characteristic of attention and more efficient performance (Lindsley, 1961). Performance by subjects in this study clearly contradicts the attention hypothesis. Subjects who have learned and are using alpha control are able to maintain control during stimulus input, as shown in Figure 3. For them, even in the practice trials, desynchrony was not necessary for perceiving and processing information.

Even Mulholland (1968), who pointed out the paradox of the attention hypothesis, predicted an initial alpha blockage, followed by rapid habituation to an auditory stimulus. His Oculomotor Efferent Command Theory states that one gives a looking "command" to the eyes when a stimulus draws his attention, and that this oculomotor event causes alpha blocking. Absence of initial alpha blockage would indicate, according to his theory, lack of an internal looking "command" in this situation.

These data can be interpreted in the light of Andersen and Andersson's (1968) predictions about alpha blocking. Based on their research with animals, they predicted that a certain amount of afferent stimulation to the thalamus is required to start alpha production and that an increased amount causes desynchrony. The afferent excitation, auditory stimulation produced by the sound of the words in this case, did not exceed the optimal level of excitation for maintaining alpha activity in the EEG. One might speculate that perhaps the optimal level, or threshold for desynchrony, was increased by alpha training in this situation. Perhaps the optimal level would have been exceeded under other circumstances, such as presentation of unexpected or stressing words. Lindsley (1961) reported that stress produces desynchrony. Whether stress would affect the EEG of a person using alpha control is unknown. Pribram (1967), in his discussion of internal and external factors in behavior emphasized the role of expectancy. He suggested that expectation serves as a homeostatic background against which sensory stimuli are appraised as novel or familiar. Registration of novelty desynchronizes the EEG. Perhaps, in this case, since subjects were expecting a word list, it was appraised as familiar, allowing them to maintain predominant alpha activity. However, this would not explain the desynchrony observed in subjects without alpha training. They would also appraise a word list as familiar if they were expecting it. It would appear that the differential response of the EEG to stimulus input is due to the training itself.

There is no question that subjects attended to the stimuli. While items may be registered in the sensory store without being attended to, some attention is necessary for a trace to be stored (Waugh & Norman, 1965). Data from early serial positions in the lists is evidence that some items were recalled from the long-term store. In this situation, the EEG was dissociated from another sign of arousal, attention. EEG arousal apparently is not a necessary concomitant of learning; in fact, EEG arousal and learning can be dissociated.

Serial Position Curves

Serial position curves for subjects in high, low, and neutral alpha were inverted U-shaped, showing clear primacy and recency effects. Storage and retrieval in both the long-term store and the short-term store were enhanced in all conditions. The significant difference in words recalled at the extremes of the curves indicates that there was a stronger recency than primacy effect. There are probably two factors operating here. First, the speed of presentation (one word per second) reduced the amount of rehearsal time for earlier items so that fewer were transferred to the long-term store. In addition, those items that were in the long-term store were harder to retrieve because of list length. A longer list produces more interference at the time of recall (Atkinson & Shiffrin, 1968).

The Alpha Index

While the Alpha Index in the high alpha condition was higher than that in the control condition, the difference was not statistically significant. An examination of the means collapsed across subjects reveals that 88% of the time was spent in alpha during high alpha instructions, and 70% of the time was spent in alpha during control instructions. The elevated baseline, due to training, brought the Alpha Index of the neutral condition up to a point close to the Index of the HA (high alpha) condition. One might argue that there was in fact no difference between subjects in these two conditions. While there may be no difference, it is possible that a ceiling effect obscured differences. The Alpha Index of 88% is very high, leaving little room for improvement. Lack of a significant difference here does not affect the meaning of these results. Subjects clearly showed better recall when they were producing more alpha activity. That subjects do show an upward shift in baseline suggests that there may be permanent changes in the EEG as a result of training.

Subjective Reports

Variability in subjects' descriptions of how they produce and suppress alpha activity indicates that either subjects control alpha in different ways, or that they are unable to label the internal states they produce to achieve control. They consistently reported that production of alpha was a more pleasant task than suppression of it.

Since it is a pleasant state, and since learning is at least as good in it, one might speculate that turning alpha on while listening to verbal information, such as lectures, might be preferable to other modes of listening. Since it is relaxing to produce alpha, it might be useful in situation of tension and stress. Perhaps reducing nervous symptoms by producing alpha may reduce anxiety.

Summary

In summary, EEG arousal did not accompany attention to stimulus words presented orally. Learning during high alpha was better than it was in low alpha, and at least as good as it is normally. These results provide another example of the EEG being dissociated from behavioral signs of arousal, and suggest that stimulus perception, storage, and recall do not correlate with gross electrical activity of the brain in any simple way.

# APPENDIX A

# INSTRUCTIONS TO SUBJECTS

Day I Training

Today you begin training in the control of alpha waves. During training sessions, you should relax in the chair with your eyes closed and remain still. Try to avoid any vigorous movements of your eyes or your body. For the first ten minutes today, you will listen to the tone that is produced when alpha is present so that you can become familiar with the sound that indicates the presence of alpha. During the ten minute session, the tone you hear will not be produced by your own alpha activity but by the machine. At the end of the 10-minute period, the automatic tone will be turned off and you will be instructed alternately to turn the tone on and off. Your task will be to find the internal state that will keep the tone on or off. When I say "start," you are to try to produce alpha which will keep the tone on. When I say "stop," you are to try to suppress alpha activity and keep the tone off. Do you have any questions?

Close your eyes and remain still while you listen to the tone.

Now you are to try to control the tone. When I say start, try to turn it on. When I say stop, try to turn it off. Start.

Day II Training

Today you continue training in the control of alpha waves. You will hear the tone for the first five minutes, after which you will be instructed alternately to start and stop alpha activity. Your task is to find the internal state that will keep the tone on or off. When I say start, you are to try to produce alpha which will keep the tone on. When I say stop you are to try to suppress alpha activity. Close your eyes, relax, and remain still while you listen to the tone.

Now you are to try to control the tone. Start.

Day III and Subsequent Training Days

Today you continue training in the control of alpha waves. You will again be instructed to turn alpha activity on and off. When I say start, you are to try to produce alpha which will keep the tone on. When I say stop, you are to try to suppress alpha activity and keep the tone off. Close your eyes, relax, and remain still while you turn alpha on and off. Start.

Practice Trials on Verbal Learning Task

Today you will practice doing the task on which you will be tested later. During practice and test sessions, you EEG will be monitored but you will not hear the tone. You will practice the verbal learning task today under three EEG conditions: High alpha, low alpha, and a neutral condition in which you should make no attempt to enhance or suppress your alpha activity. First you will be instructed to produce and maintain one of these three conditions. After it is established, you will hear a series of words followed by a tone. This tone is your signal to recall the words in any order. After the tone sounds, you need no longer be concerned with your EEG pattern. It is while the words are being presented that it is important for you to maintain your EEG pattern. As soon as you hear the tone, recall as many of the words as possible in any order.

You will have two tasks: first, to maintain your EEG pattern, and second, to recall the words after the bell sounds. Do you have any questions?

Before starting you will have two warm-up sets of start and stop instructions with feedback, followed by two sets without the tone. Warm-up begins now. Start.

Your practice test in the neutral condition is first. Make no attempt to produce or suppress alpha. Produce the neutral condition.

Now you practice in alpha. Start alpha activity.

Now you will practice in the low alpha condition. Stop alpha activity.

Neutral Test Instructions

Today you will be tested in a neutral EEG condition. Make no effort to produce or suppress alpha activity. Produce the neutral condition.

High Alpha Test Instructions

Today you will be tested in the high alpha condition. When instructed, produce alpha and maintain it until you hear the bell, which is your signal to recall the words. Before testing you will have two start-stop sessions with feedback. Warm-up begins now. Start.

Remember to maintain alpha while words are being presented. Now produce alpha.

Low Alpha Test Instructions

Today you will be tested in the low alpha condition. When instructed, you should suppress alpha and maintain suppression until you hear the bell which is your signal to recall the words in any order.

Before testing, you will have two start-stop sessions with feedback. The warm-up will begin now. Start.

Now suppress alpha.

# APPENDIX B

# WORD LISTS AND ORDER OF PRESENTATION

ORDER OF LIST PRESENTATION

| Subject | Day | Tapes | Instruction Condition |
|---|---|---|---|
| 1 | 1 | 1,2 | CC |
| | 2 | 3,4 | HA |
| | 3 | 5,6 | LA |
| | 4 | 7,8 | CC |
| 2 | 1 | 8,6 | CC |
| | 2 | 4,2 | HA |
| | 3 | 1,3 | LA |
| | 4 | 5,7 | CC |
| 3 | 1 | 2,5 | CC |
| | 2 | 1,3 | LA |
| | 3 | 7,8 | HA |
| | 4 | 6,4 | CC |
| 4 | 1 | 5,7 | CC |
| | 2 | 6,8 | LA |
| | 3 | 4,1 | HA |
| | 4 | 3,2 | CC |

Each tape consisted of five ten-word lists.

## PRACTICE WORDS

| I | II | III | IV | V |
|---|---|---|---|---|
| ROAM | ZERO | DUNE | INCH | BELT |
| HARP | FISH | WIRE | CORN | DISH |
| BEAR | LORE | KNOB | ZEST | TOOL |
| TOAD | BIAS | MENU | MAZE | SIGN |
| DOOM | COLT | TIDE | JUNK | NAPE |
| PACT | SHOP | BELL | HAIR | VINE |
| KING | HEMP | SOAP | TANK | JOWL |
| NEST | DUSK | GAME | VASE | KILT |
| SOOT | NOTE | FIFE | RICE | WEEK |

| VI | VII | VIII | IX | X |
|---|---|---|---|---|
| ROLE | LAMB | PEAR | FROG | MONK |
| VEIL | MOON | WREN | GIST | DIAL |
| MOAT | JOLT | KNEE | NEWS | TINT |
| ACRE | WASP | OPUS | BIRD | JOKE |
| GASH | FORT | MAIL | PEER | LYNX |
| EDGE | ITCH | PART | CLAY | SIZE |
| SALT | GIRL | TANG | MALT | GONG |
| KILL | EVIL | ROSE | HARM | ODOR |
| BOAR | COAT | GLUE | SLOP | RATE |

# TEST WORDS

## LIST I

| | | | | |
|---|---|---|---|---|
| BANK | CANDY | FATE | DUKE | TRAP |
| PORCH | MILL | SHEEP | MONEY | IGLOO |
| TALK | AMEBA | GARB | FOOD | PALM |
| ANGER | SPAN | WHEEL | LILY | RODEO |
| ROOF | ENEMY | MINK | BULK | CASE |
| MUSIC | PIPE | OASIS | RIVER | UNCLE |
| DUTY | JELLY | BEAN | CRIB | BONE |
| STORM | LARK | DAISY | FLASH | GLOBE |
| LUNG | FABLE | CHIN | HEEL | DAWN |

## LIST II

| | | | | |
|---|---|---|---|---|
| SWAMP | GOAT | PURSE | JURY | MILE |
| YARN | SAUCE | VOLT | QUEST | BROOM |
| GOOSE | CRAB | CHAIR | PATH | SWAN |
| WART | ALTO | TREE | CITY | GUILT |
| AGENT | FLAG | STORK | FORK | COMA |
| MOSS | PRIDE | FOOL | SLUSH | THORN |
| DRAMA | ZINC | LILAC | RANK | WORD |
| PAWN | HORSE | DOSE | THIEF | HABIT |
| BROTH | LAMP | APRON | CAPE | PILL |

LIST III

| | | | | |
|---|---|---|---|---|
| SNOB | CANOE | CAKE | GLORY | ETHER |
| MELON | FLAW | POLIO | CAMP | SLUM |
| RUBY | LIVER | DOOR | BLOOD | BRUTE |
| BRINK | BUNK | BEACH | TWIG | KITE |
| PANG | DIARY | LION | SALAD | GRAVY |
| EVENT | ROOM | TRUCE | WIFE | MULE |
| WARD | TRIBE | RACK | AROMA | DRESS |
| MERCY | HAZE | GRASS | HERO | ITEM |
| HOST | MOTOR | SHOE | AREA | TENOR |

LIST IV

| | | | | |
|---|---|---|---|---|
| FISH | APEX | SIDE | LAKE | PEST |
| YACHT | THORN | IRONY | BREAD | CHOIR |
| LOBE | DOVE | TOGA | MOTH | ZONE |
| RIOT | HOBO | ACID | OMEN | IRIS |
| ACTOR | MOOD | CHEF | JADE | LANE |
| TUNE | PUPPY | BEAST | FLOOD | WATER |
| DEATH | NECK | GLUE | AUNT | HOME |
| MESH | GREED | TRUCK | BLOOM | IDIOT |
| SOFA | SKIN | PAGE | DINE | YEAR |

LIST V

| | | | | |
|---|---|---|---|---|
| DIRT | MARSH | GATE | BEACH | CAST |
| SUGAR | DEED | RESIN | RASH | ERROR |
| GANG | WORLD | FACE | FLASK | GIFT |
| COLON | FOOT | PIANO | WOLF | BOARD |
| TERM | CLERK | VEST | CLOAK | HOOF |
| FILTH | IDEA | BACON | MINT | MASON |
| RIND | VIGOR | CART | TOWER | TONE |
| DIVER | PLUM | THEFT | SLAB | ANGLE |
| WORD | SNAIL | SAND | JUDGE | OVEN |

LIST VI

| | | | | |
|---|---|---|---|---|
| RAMP | SOFA | RULER | FURY | PANIC |
| LEMON | MONTH | VEAL | VIRUS | MEAL |
| POET | LAND | BLISS | DESK | TIGER |
| NOON | BRIDE | FOIL | MEAT | DOLL |
| DUET | TASK | HONEY | GLOVE | VILLA |
| SHOCK | ELBOW | LINE | STAG | SASH |
| WINE | ARMY | STAFF | ACORN | BLADE |
| MERCY | PEACH | GUST | HOOP | ZEAL |
| GERM | DECK | CARGO | TULIP | CHIEF |

LIST VII

| | | | | |
|---|---|---|---|---|
| CORD | BANJO | BRAT | SLIT | HAND |
| MEDIA | SICK | OPERA | GAVEL | LARVA |
| BEEF | CANAL | TROUT | CLAN | EPIC |
| HUMOR | GRAM | LIMB | POPPY | SHARK |
| SUIT | TUMOR | SPORT | LOFT | FERN |
| TOWEL | VERB | FUSE | BAKER | BENCH |
| VAMP | QUEEN | ALLEY | DRAM | NAVY |
| DENIM | DUDE | TOWN | SKULL | PLATE |
| NODE | MOTTO | CHICK | WISP | TUBE |

LIST VIII

| | | | | |
|---|---|---|---|---|
| PENNY | BULB | MIRTH | BROW | CAMEL |
| BATH | FAULT | JAIL | TONIC | SLOT |
| TRUCK | DUKE | SCARF | GUST | BERRY |
| DOSE | POEM | FACT | CABIN | RAFT |
| FRUIT | UNIT | EAGLE | HALL | TEAM |
| GOWN | SKULL | KISS | SHIRT | SPINE |
| CHIMP | LUCK | DIGIT | MOLE | LIFE |
| SOUP | CLOCK | TART | ROBOT | YARD |
| RADAR | RAIL | ADULT | FLAP | PUPIL |

# WORD LIST FOR HEARING TEST

1. cold
2. shame
3. calf
4. power
5. boat
6. hotel
7. beet
8. party
9. dual
10. rosin
11. atom
12. honor
13. ghost
14. loot
15. proxy
16. gent
17. rode
18. woman
19. flee
20. truth
21. ache
22. vapor
23. nose
24. coast
25. child

# APPENDIX C

# WORDS RECALLED CORRECTLY AND PERCENT TIME IN ALPHA

# RECALL DATA AND PERCENT TIME IN ALPHA

| $S_1$ | Number Words Recalled | | | | % Time in Alpha | | | |
|---|---|---|---|---|---|---|---|---|
| List | HA | LA | $CC_1$ | $CC_2$ | HA | LA | $CC_1$ | $CC_2$ |
| 1 | 2 | 2 | 1 | 1 | 88 | 29 | 56 | 86 |
| 2 | 2 | 1 | 0 | 1 | 100 | 0 | 12 | 82 |
| 3 | 2 | 0 | 1 | 2 | 64 | 7 | 70 | 100 |
| 4 | 4 | 1 | 1 | 2 | 62 | 5 | 73 | 62 |
| 5 | 3 | 2 | 0 | 1 | 44 | 9 | 47 | 95 |
| 6 | 2 | 0 | 1 | 1 | 70 | 0 | 47 | 100 |
| 7 | 4 | 1 | 1 | 1 | 53 | 15 | 82 | 90 |
| 8 | 4 | 1 | 1 | 2 | 68 | 50 | 72 | 80 |
| 9 | 2 | 2 | 1 | 1 | 100 | 5 | 82 | 100 |
| 10 | 3 | 1 | 1 | 3 | 100 | 18 | 76 | 100 |

| $S_2$ | Number Words Recalled | | | | % Time in Alpha | | | |
|---|---|---|---|---|---|---|---|---|
| List | HA | LA | $CC_1$ | $CC_2$ | HA | LA | $CC_1$ | $CC_2$ |
| 1 | 4 | 6 | 4 | 3 | 100 | 0 | 90 | 53 |
| 2 | 5 | 6 | 5 | 6 | 100 | 14 | 95 | 100 |
| 3 | 3 | 5 | 5 | 5 | 95 | 0 | 100 | 71 |
| 4 | 5 | 5 | 3 | 4 | 95 | 12 | 100 | 95 |
| 5 | 6 | 6 | 4 | 5 | 76 | 0 | 100 | 85 |
| 6 | 5 | 3 | 4 | 5 | 100 | 14 | 100 | 100 |
| 7 | 6 | 4 | 5 | 4 | 100 | 7 | 100 | 94 |
| 8 | 5 | 4 | 5 | 5 | 100 | 0 | 100 | 94 |
| 9 | 5 | 5 | 4 | 3 | 95 | 7 | 100 | 50 |
| 10 | 5 | 4 | 3 | 5 | 100 | 5 | 80 | 82 |

RECALL DATA AND PERCENT TIME IN ALPHA

| S3 | Number Words Recalled | | | | % Time in Alpha | | | |
|---|---|---|---|---|---|---|---|---|
| List | HA | LA | $CC_1$ | $CC_2$ | HA | LA | $CC_1$ | $CC_2$ |
| 1 | 7 | 7 | 5 | 3 | 100 | 0 | 83 | 35 |
| 2 | 7 | 5 | 5 | 6 | 77 | 0 | 50 | 62 |
| 3 | 7 | 4 | 6 | 5 | 80 | 0 | 100 | 76 |
| 4 | 5 | 6 | 8 | 7 | 100 | 0 | 100 | 59 |
| 5 | 7 | 6 | 5 | 6 | 100 | 0 | 50 | 88 |
| 6 | 8 | 4 | 6 | 5 | 100 | 0 | 89 | 100 |
| 7 | 7 | 5 | 5 | 7 | 92 | 0 | 94 | 14 |
| 8 | 7 | 7 | 6 | 7 | 92 | 0 | 12 | 50 |
| 9 | 5 | 7 | 6 | 5 | 100 | 5 | 73 | 86 |
| 10 | 6 | 6 | 6 | 6 | 100 | 0 | 78 | 100 |

| S4 | Number Words Recalled | | | | % Time in Alpha | | | |
|---|---|---|---|---|---|---|---|---|
| List | HA | LA | $CC_1$ | $CC_2$ | HA | LA | $CC_1$ | $CC_2$ |
| 1 | 5 | 4 | 4 | 7 | 100 | 0 | 0 | 100 |
| 2 | 6 | 4 | 7 | 6 | 88 | 0 | 0 | 95 |
| 3 | 6 | 5 | 6 | 6 | 100 | 0 | 5 | 73 |
| 4 | 6 | 4 | 3 | 8 | 92 | 0 | 90 | 80 |
| 5 | 7 | 5 | 5 | 6 | 95 | 0 | 50 | 70 |
| 6 | 6 | 5 | 6 | 7 | 90 | 0 | 100 | 0 |
| 7 | 7 | 5 | 5 | 7 | 66 | 0 | 0 | 75 |
| 8 | 5 | 5 | 6 | 5 | 100 | 0 | 0 | 100 |
| 9 | 7 | 5 | 6 | 6 | 100 | 0 | 66 | 47 |
| 10 | 4 | 4 | 6 | 7 | 71 | 0 | 0 | 68 |

# APPENDIX D

# SERIAL POSITION ERRORS

| | | Condition | | |
|---|---|---|---|---|
| | | HA | LA | CC (Mean) |
| | 1 | 13 | 20 | 16.5 |
| | 2 | 22 | 27 | 23 |
| | 3 | 20 | 24 | 29 |
| | 4 | 23 | 28 | 22 |
| Serial Position | 5 | 23 | 25 | 26 |
| | 6 | 16 | 27 | 19 |
| | 7 | 18 | 19 | 15.5 |
| | 8 | 13 | 19 | 16.5 |
| | 9 | 8 | 10 | 11.5 |

# APPENDIX E

## ALPHA INDEX SAMPLE FOR RELIABILITY ESTIMATE

ALPHA INDEX SAMPLES FOR RELIABILITY ESTIMATE

| Experimenter | Independent Judge |
|---|---|
| 30 | 30 |
| 24 | 26.5 |
| 6 | 7 |
| 30 | 30 |
| 23.5 | 28.5 |
| 25.5 | 28.5 |
| 19.5 | 22.5 |

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